Early Results from the Characterization of JET-X, Polished Silicon Optics and an Off-Plane Reflection Grating at the PANTER X-ray Test Facility

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14th international workshop on astronomical x-ray optics — December 6, 2023

Thanks to:

Penn State: Randall McEntaffer, Bridget O'meara, James Tutt, Jake McCoy

University of Iowa: Casey Deroo

PANTER: Vadim Burwitz, Gisela Hartner, Thomas Schmidt, Andreas Langmeier, Thomas Müller, Bernd Budau, Andreas Langmeier, Suri Rukdee, Stefan Passlack, entire PANTER team

The Open University: Andrew Holland, Daniel Evan

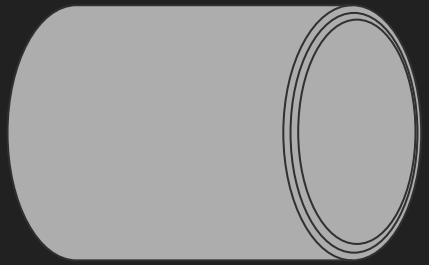
XCAM: Karen Holland, David Colebrook, David Gopinath

The Campaign

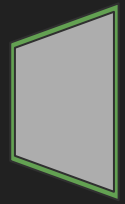
- Six week characterization campaign that took place over the October and November of this year at the PANTER X-ray test facility in Neuried, Germany
- Confirm that both the OGRE and the “Pathfinder OGRE” spectrometers meet performance requirements
    - R > 1500 across entire soft x-ray bandpass (~10 - 55 Å) and goal of R > 2000 at select energies (Donovan et al 2019)
- “Pathfinder OGRE” will use the JET-X optic (Joint European Telescope for X-ray astronomy) to replace the Monocrystalline silicon optics that will be flown on OGRE
- Source used for the duration of the campaign was Al-Kα (1.49 keV)

Schedule

- Performance test of JET-X
- Comparing to calibration done in 1996 and 2012 test



JET-X



Detector

Schedule

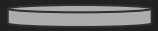
- Illuminated a 30 degree subannulus of the 2nd shell of JET-X

JET-X Grating Detector

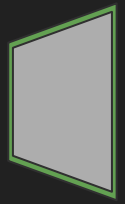
Schedule

- Swapped JET-X with a two-shell sub-annulus of polished silicon optics (PSOs)
- Frown configuration

PSO



Grating



Detector

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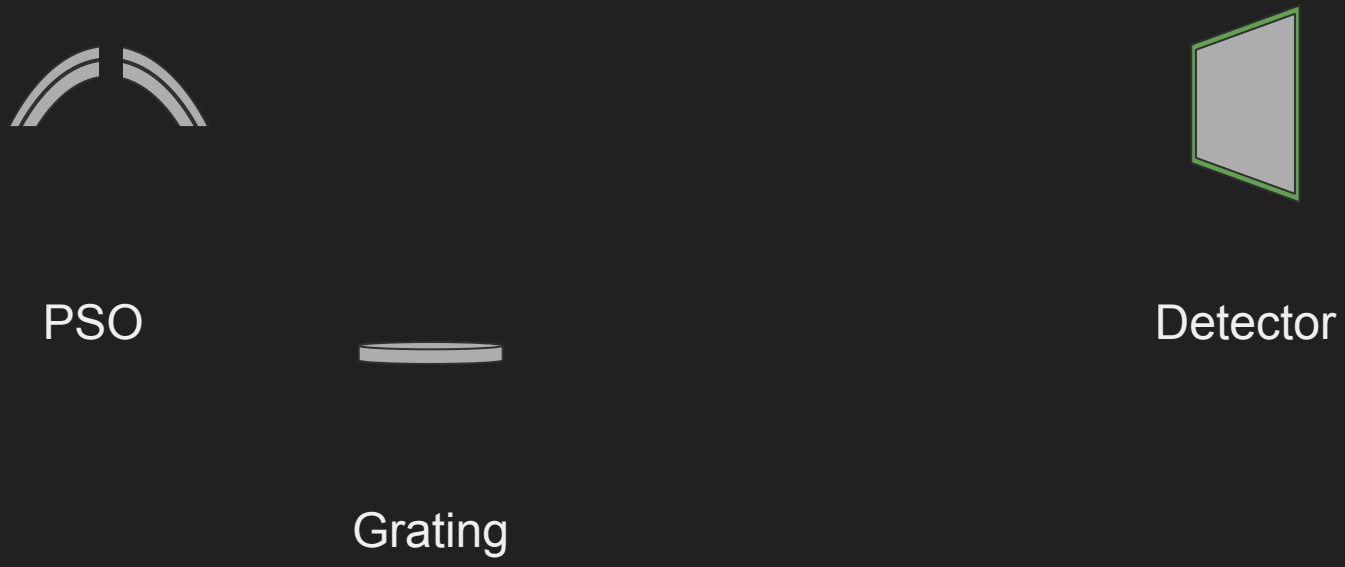


Schedule

- Moved grating back to characterize it with PSO

PSO

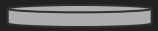
Grating

Detector

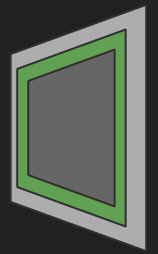
Schedule

- Added XCAM+OU EM-CCD to test entire OGRE spectrometer

PSO



Grating

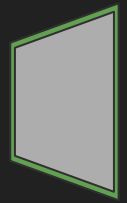


XCAM

Schedule

- In late November, PSO was also tested in smile and side configuration

PSO



Detector

Schedule

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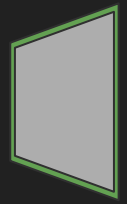
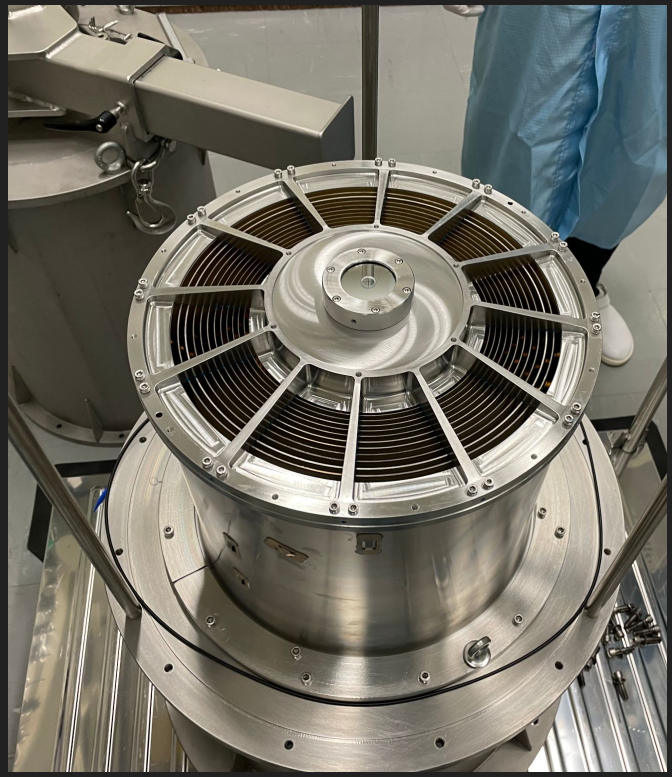
PSO



Detector

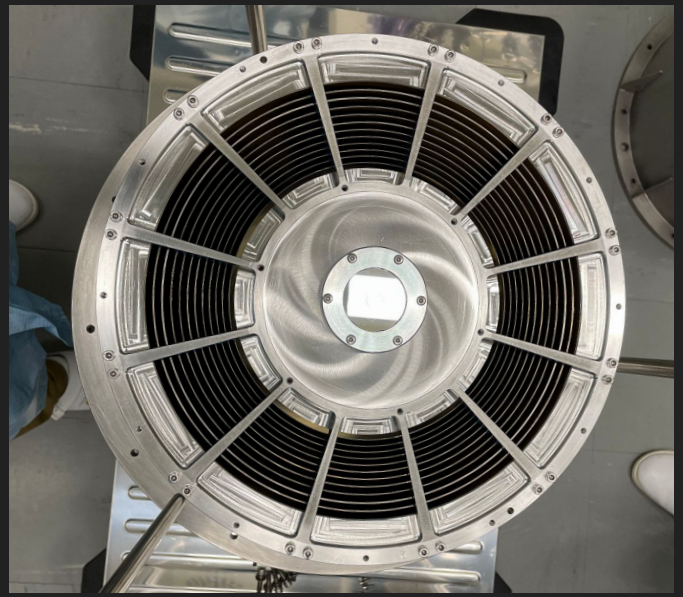
The JET-X Optic

- Joint European Telescope for X-ray astronomy
  - Developed by the Italian Space Agency (ASI) in 1994 for the Spectrum-X-γ Space Observatory
  - Second flight module
  - It was tested in 2012 (also at PANTER) to determine its performance after 16 years of storage

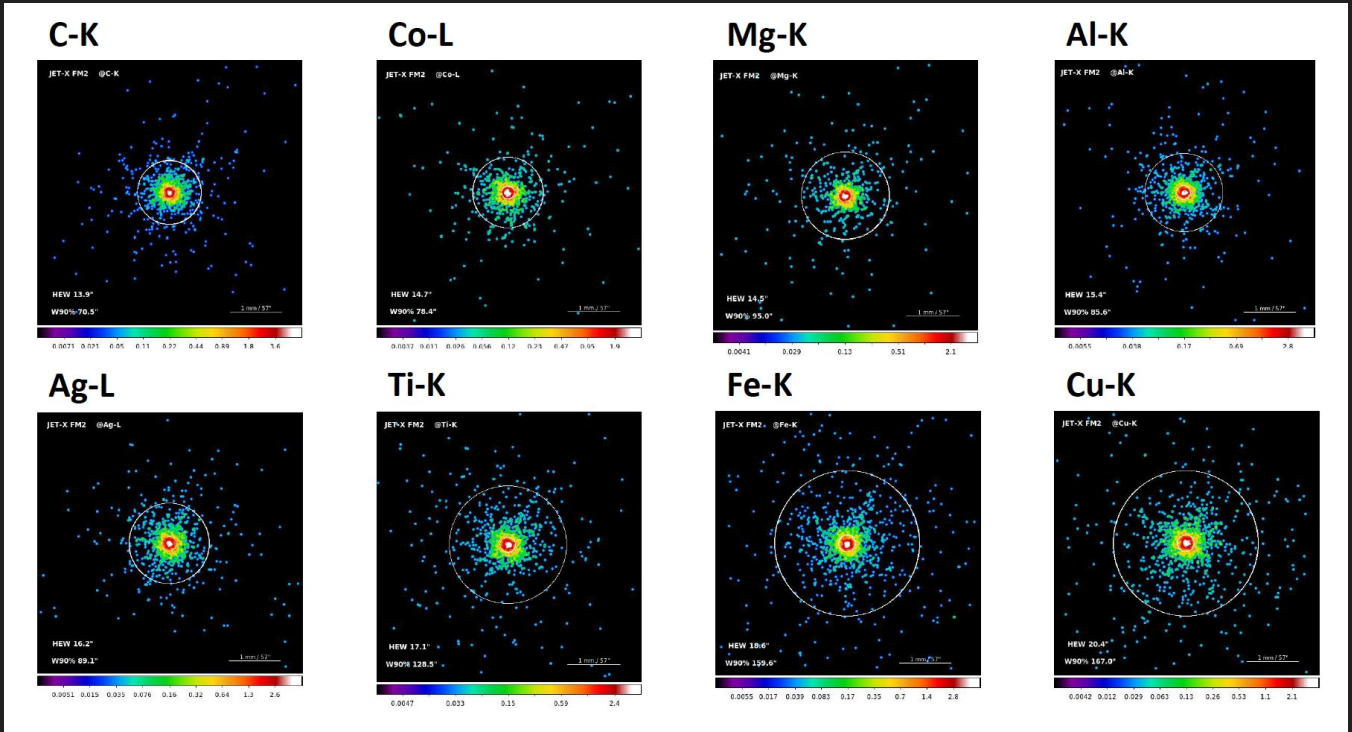


Performance of the JET-X Optic

- Same focal length as monocrystalline silicon optics/ polished silicon optics (PSOs)
- Worse angular resolution than (~15” vs ~3”) than PSOs
- But more effective area



Performance of the JET-X Optic



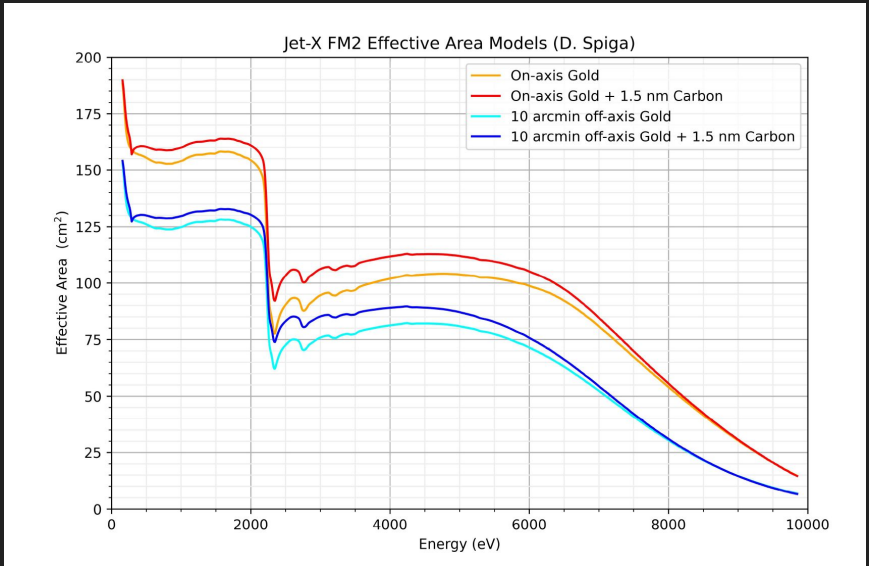
Angular Resolution of JET-X

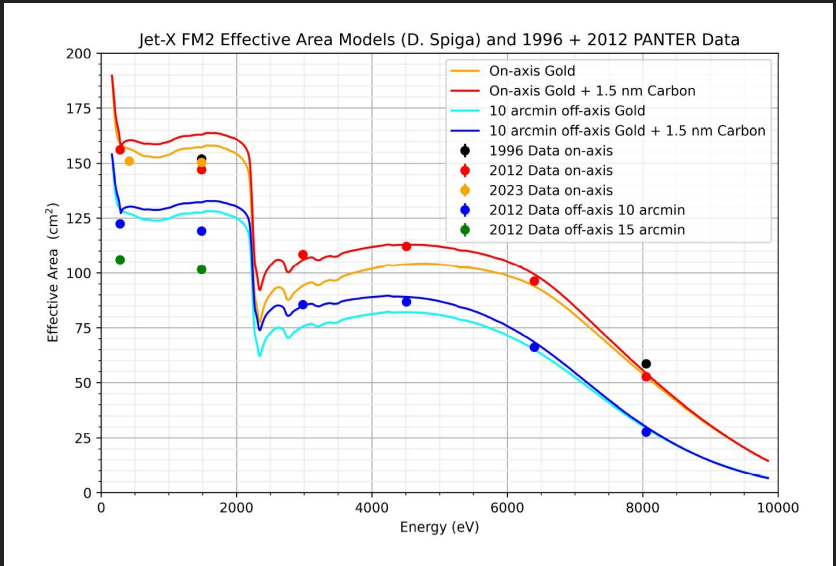
Year	**Detector**	**C-K** 0.28 keV	**Co-L** 0.78 keV	**Mg-K** 1.25 keV	**Al-K** 1.49 keV	**Ag-L** 2.98 keV	**Ti-L** 4.51 keV	**Fe-K** 6.40 keV	**Cu-K** 8.05 keV
1996 HEW (arcsec)	MOS				14.6				18.8
2012 HEW (arcsec)	TRoPIC				15.7 ± 0.4	16.8 ± 0.4	18.0 ± 0.6	20.4 ± 0.9	20.8 ± 0.7
2023 HEW (arcsec)	TRoPIC	13.9 ± 0.5	14.7 ± 0.8	14.5 ± 0.6	15.4 ± 0.8	16.2 ± 0.6	17.1 ± 0.8	18.6 ± 0.8	20.4 ± 1.0
	PIXI	13.9 ± 0.5		14.8 ± 0.3	14.6 ± 0.3		16.6 ± 0.8		

Consistent with previous measurements

1996 & 2012 values taken from Spiga et al (2014)
2023 values taken with the help of the PANTER team

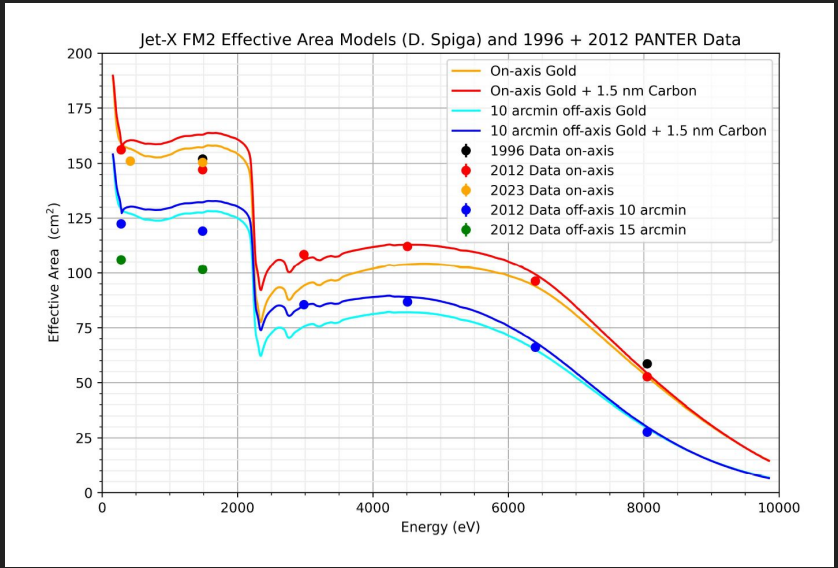
Effective Area of JET-X

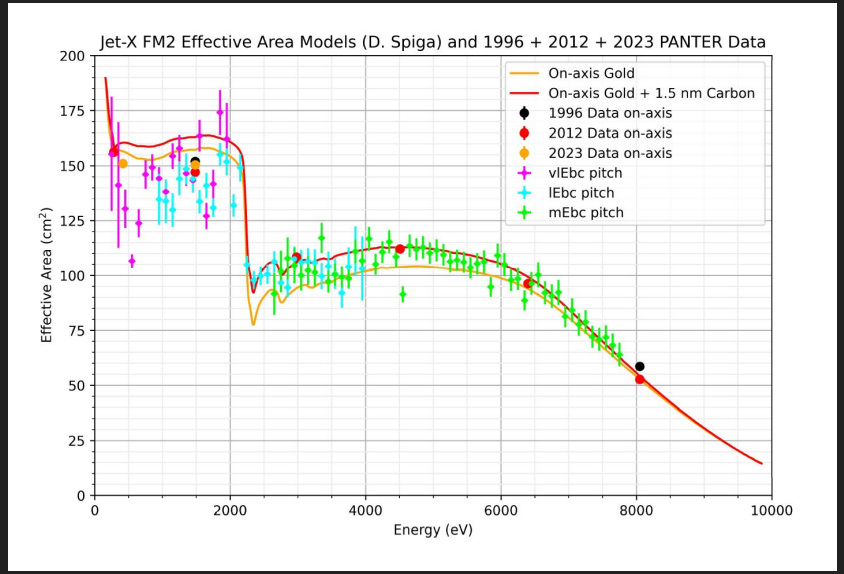




Provided by the PANTER team;
Using values from Spiga et al (2014)

Effective Area of JET-X





Provided by the PANTER team;
Using values from Spiga et al (2013)

Penn State X-ray Grating

- Blazed reflection gratings
- Aberration-correcting with a radial profile
- Mounted in the Off-plane
  - Yaw = 0.98
- Blaze is 33° — putting efficiency into 13th order when in Littrow

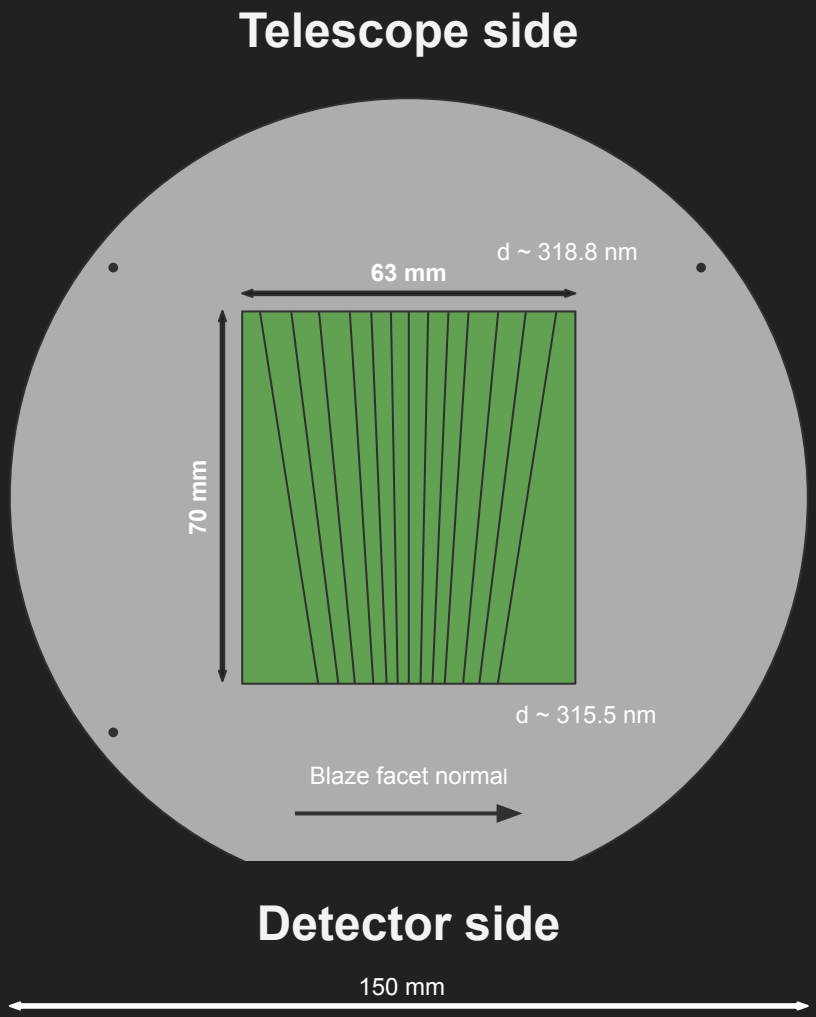
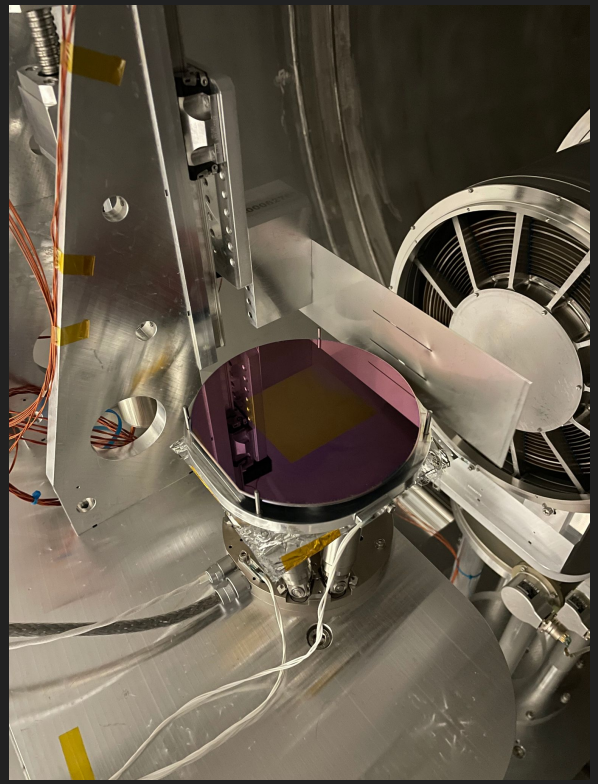
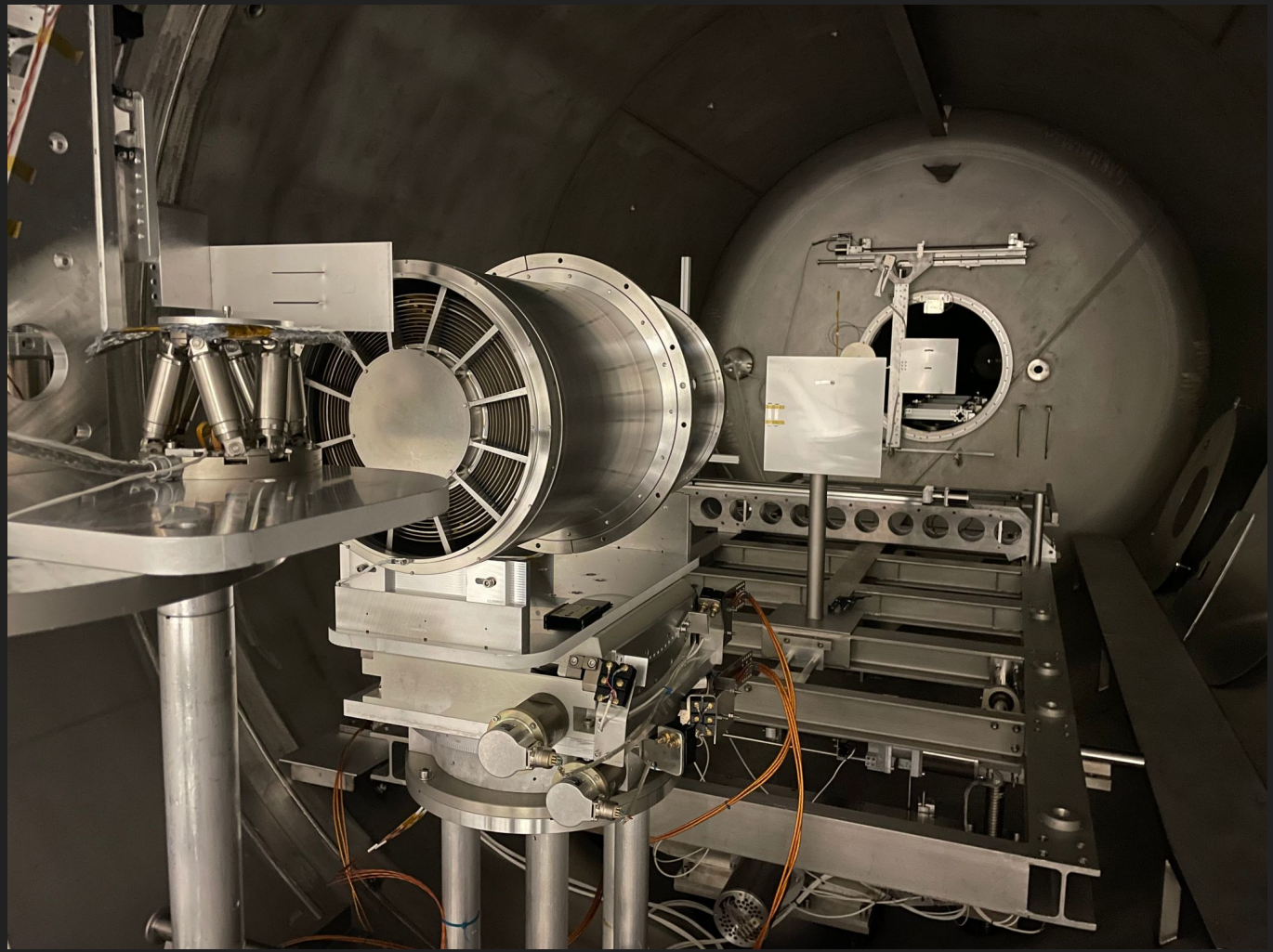
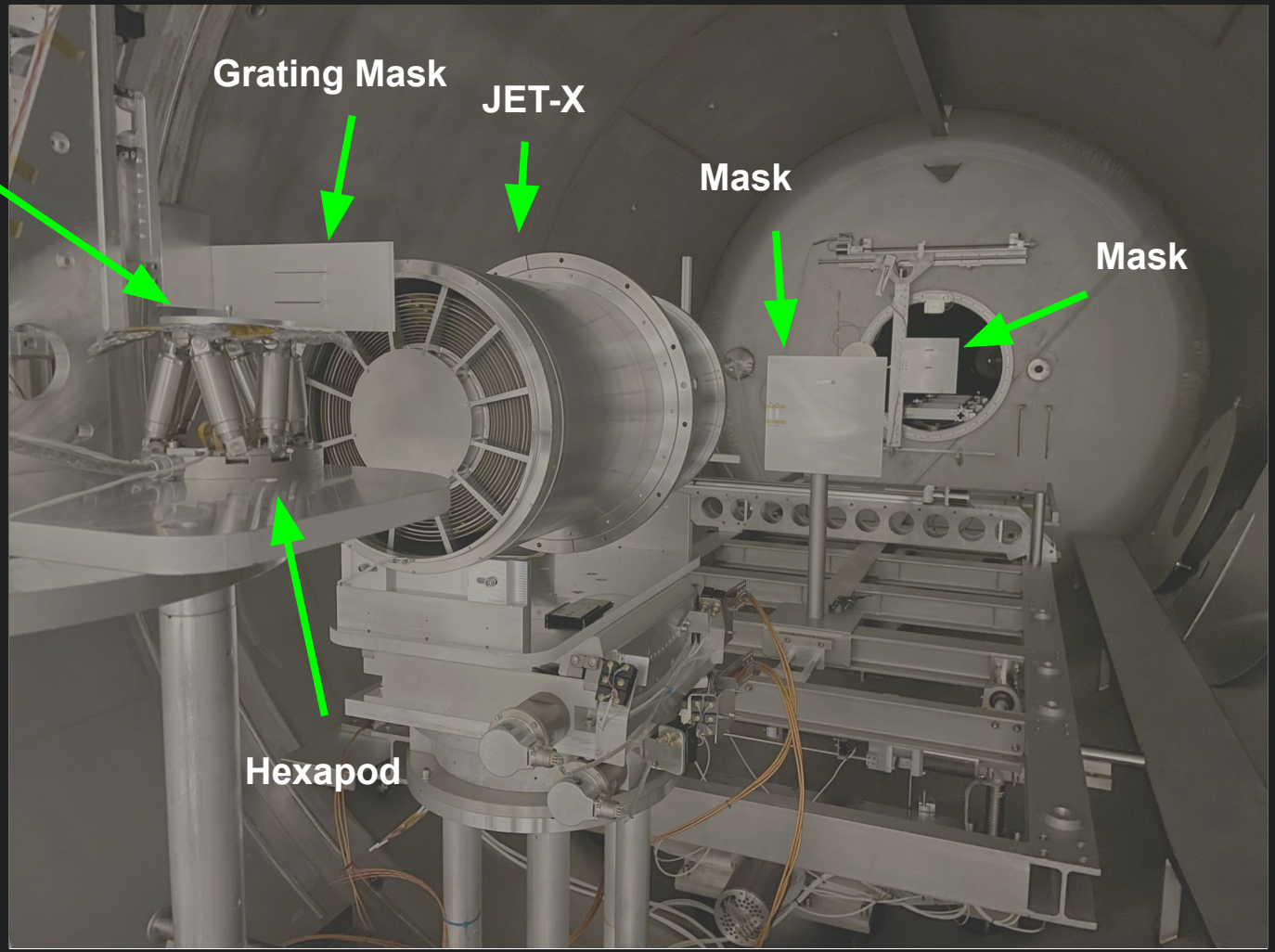


Figure adapted from O'Meara

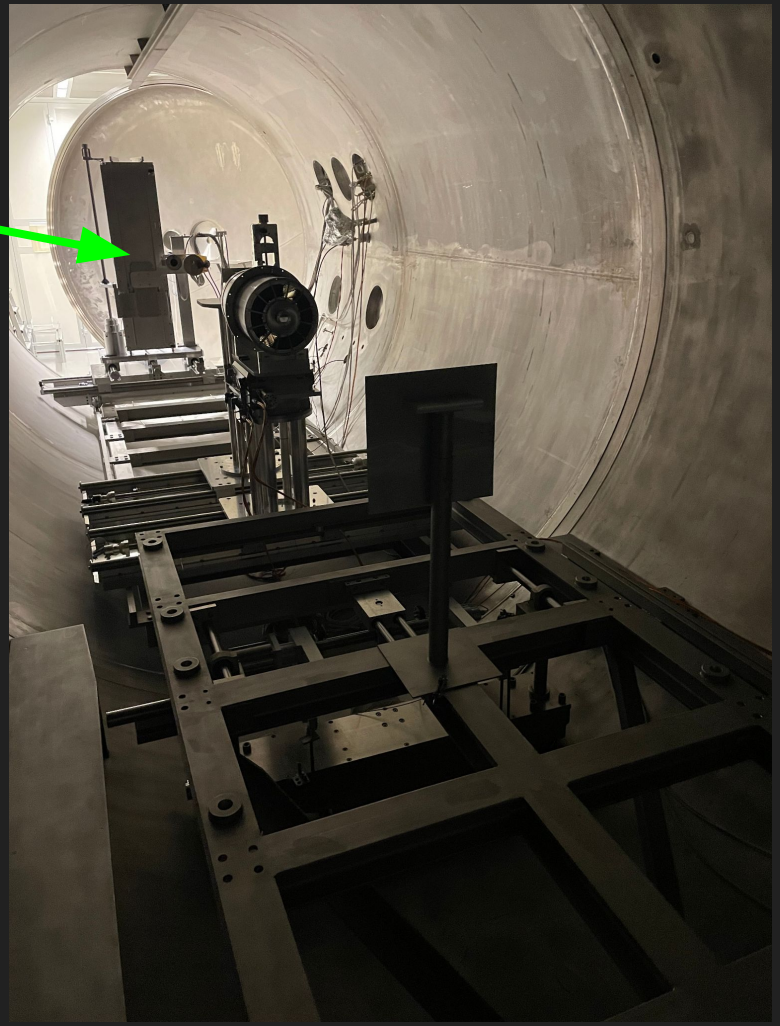
OPG (Off-plane Grating) Installation





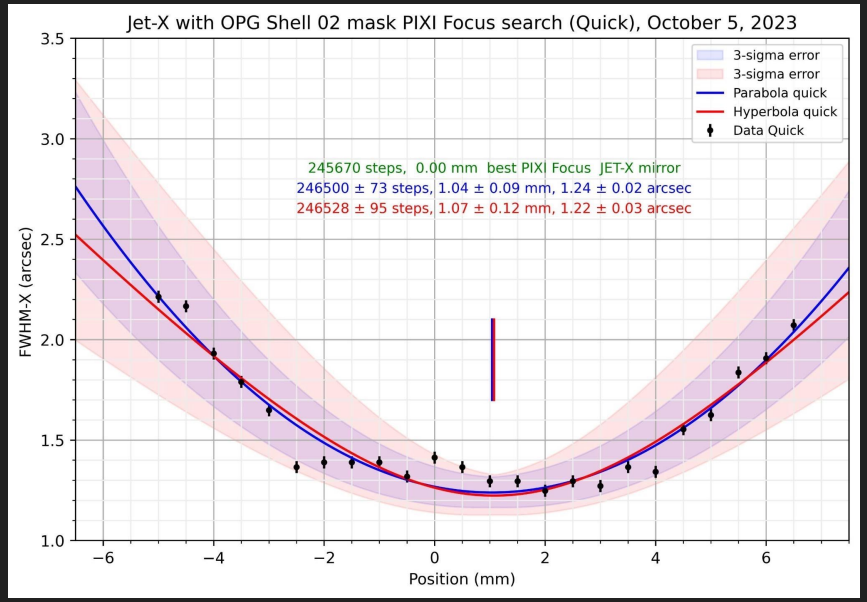

Grating
Grating Mask
JET-X
Mask
Mask
Hexapod

TRoPIC and PIXI

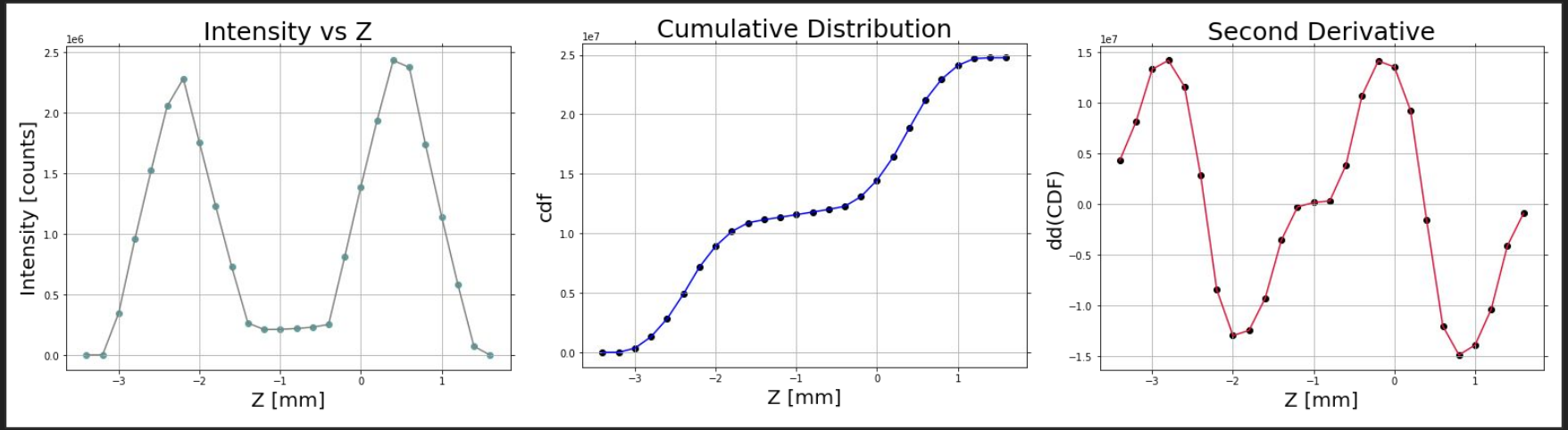


Alignment

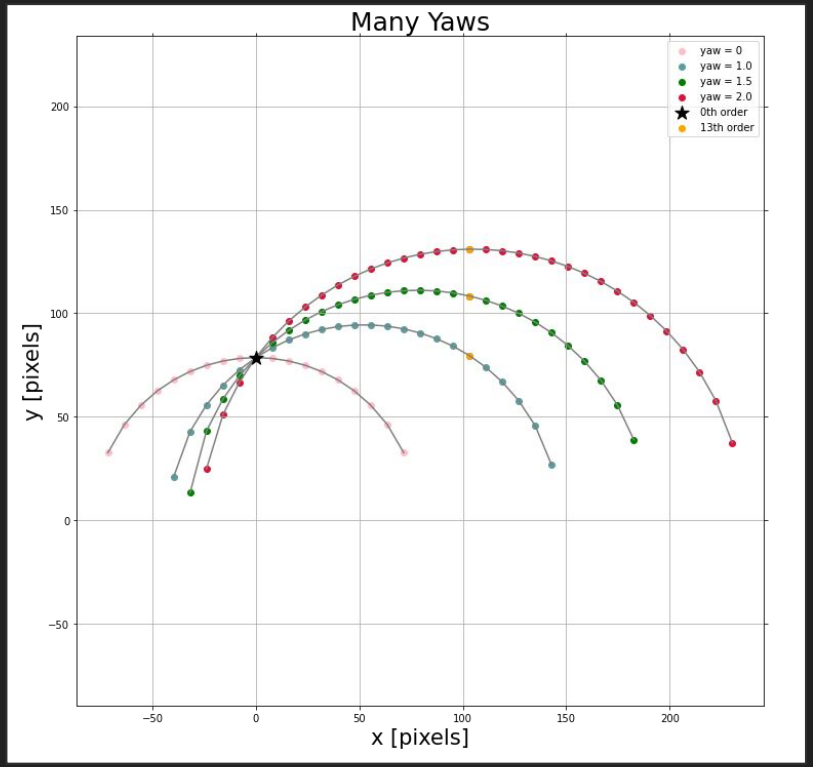
- Illuminated a 30 degree subaperature of the second shell of JET-X
- Aligned grating mask by finding optimal intensity
- Focus search
- Pitch scan
- Z-Scan
- Yaw-scan
- “Fine yaw” scan
- Did not align in roll because the image did not appear to have roll misalignment; for the sake of time

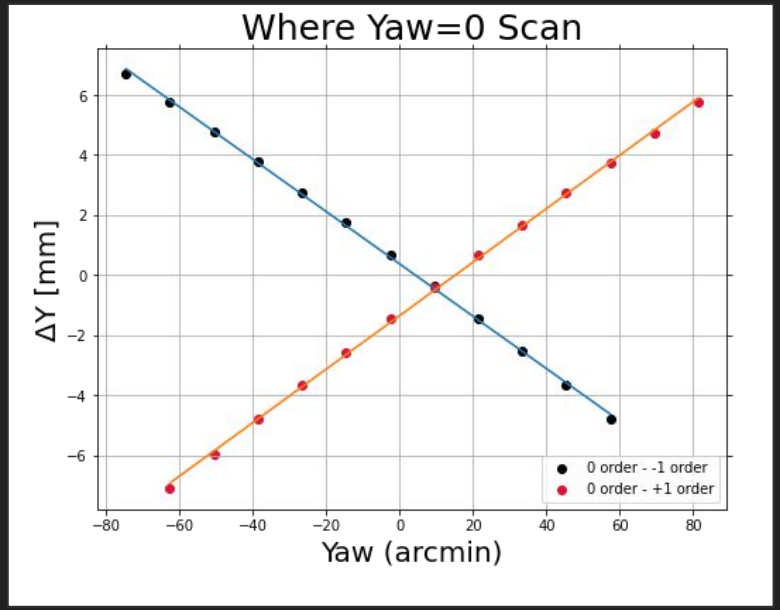


Alignment: Z-scan

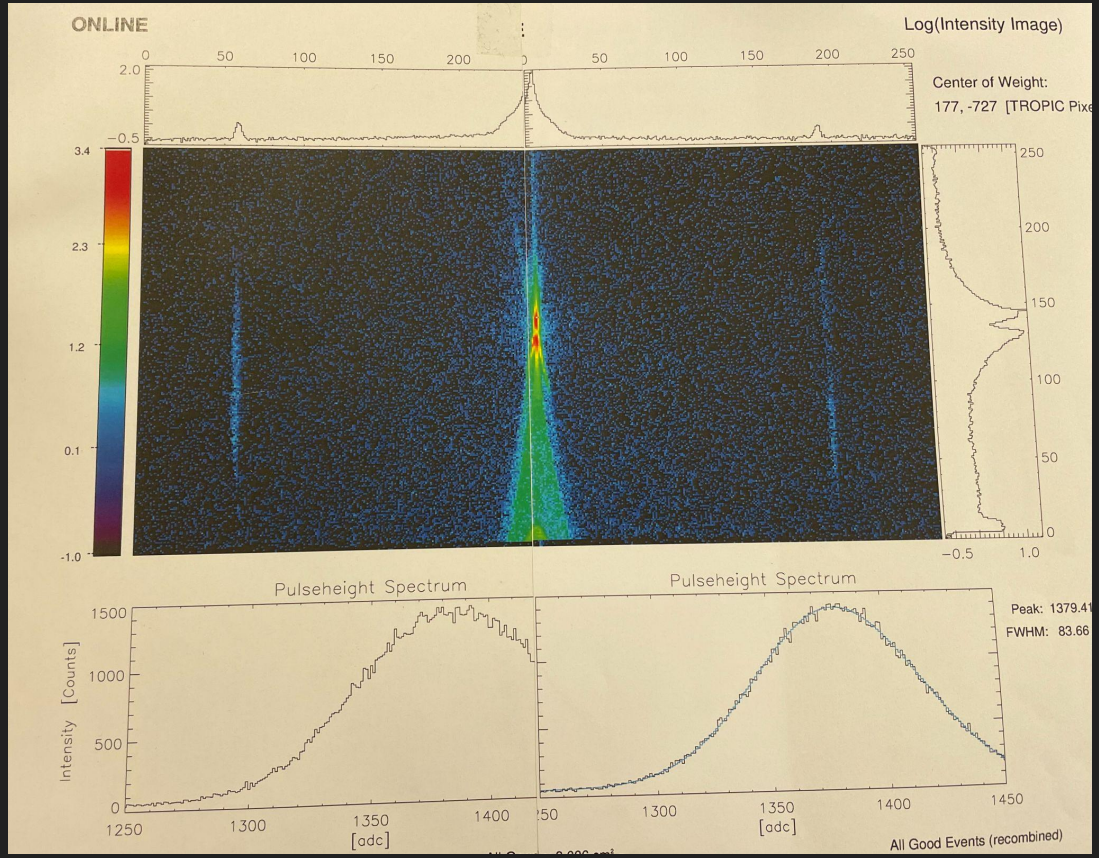


Alignment: Yaw scan

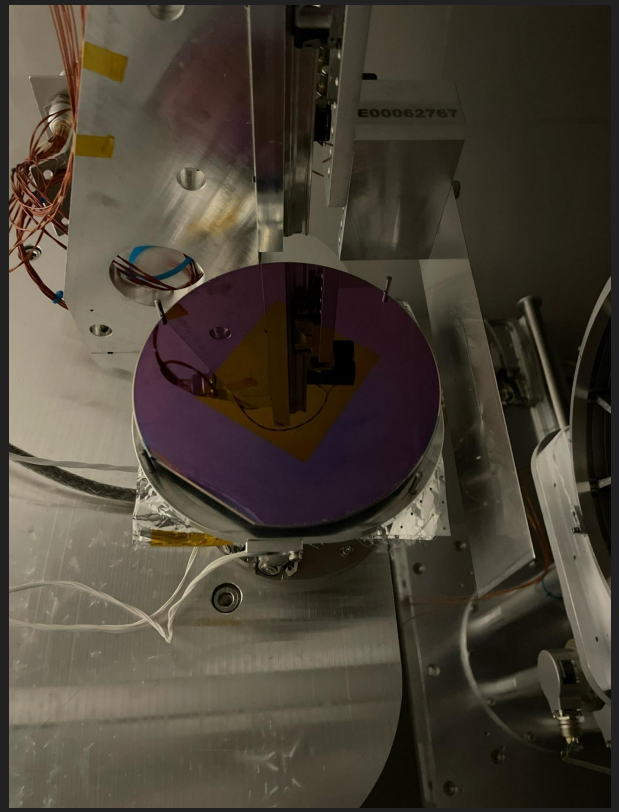


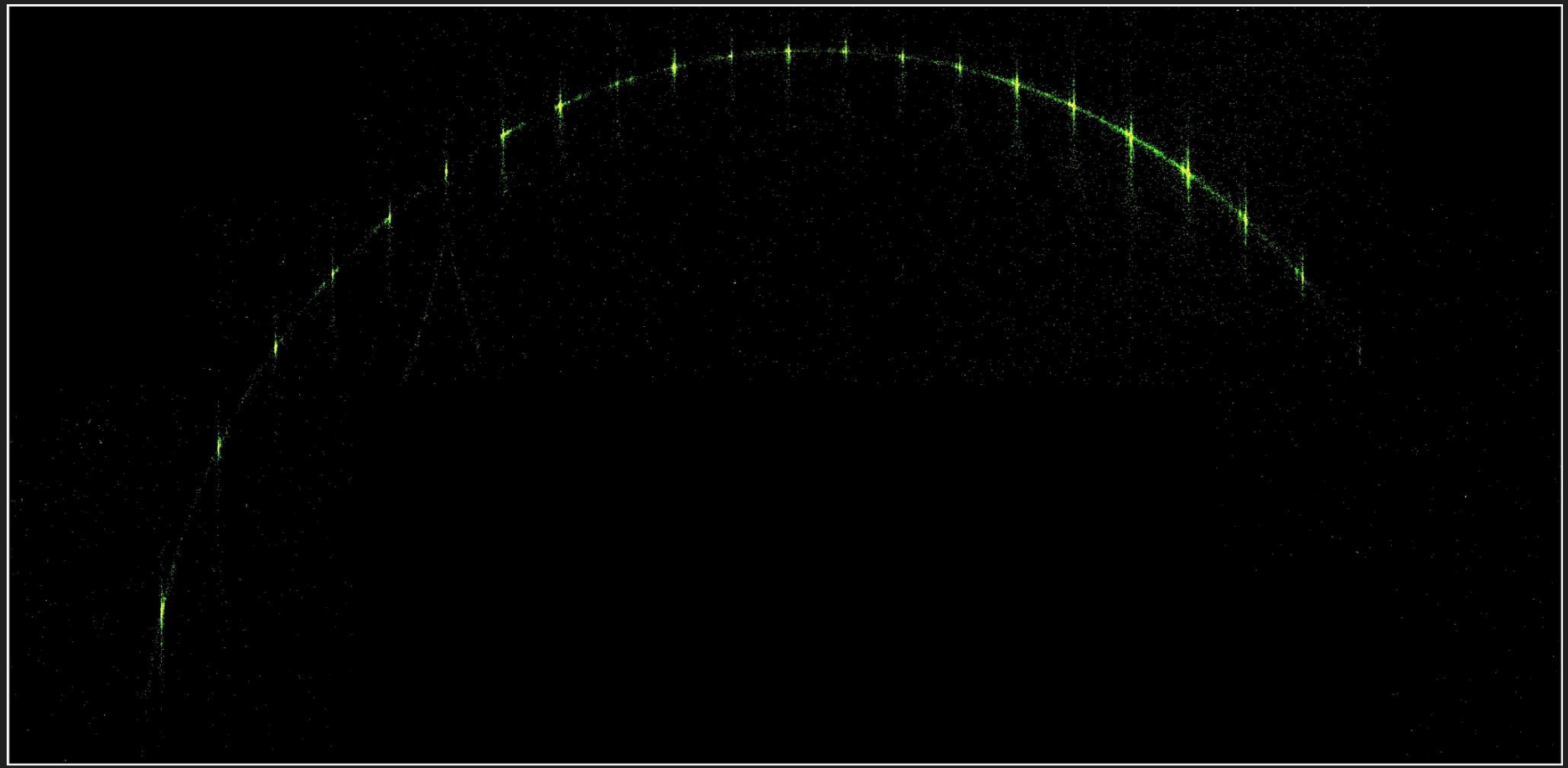


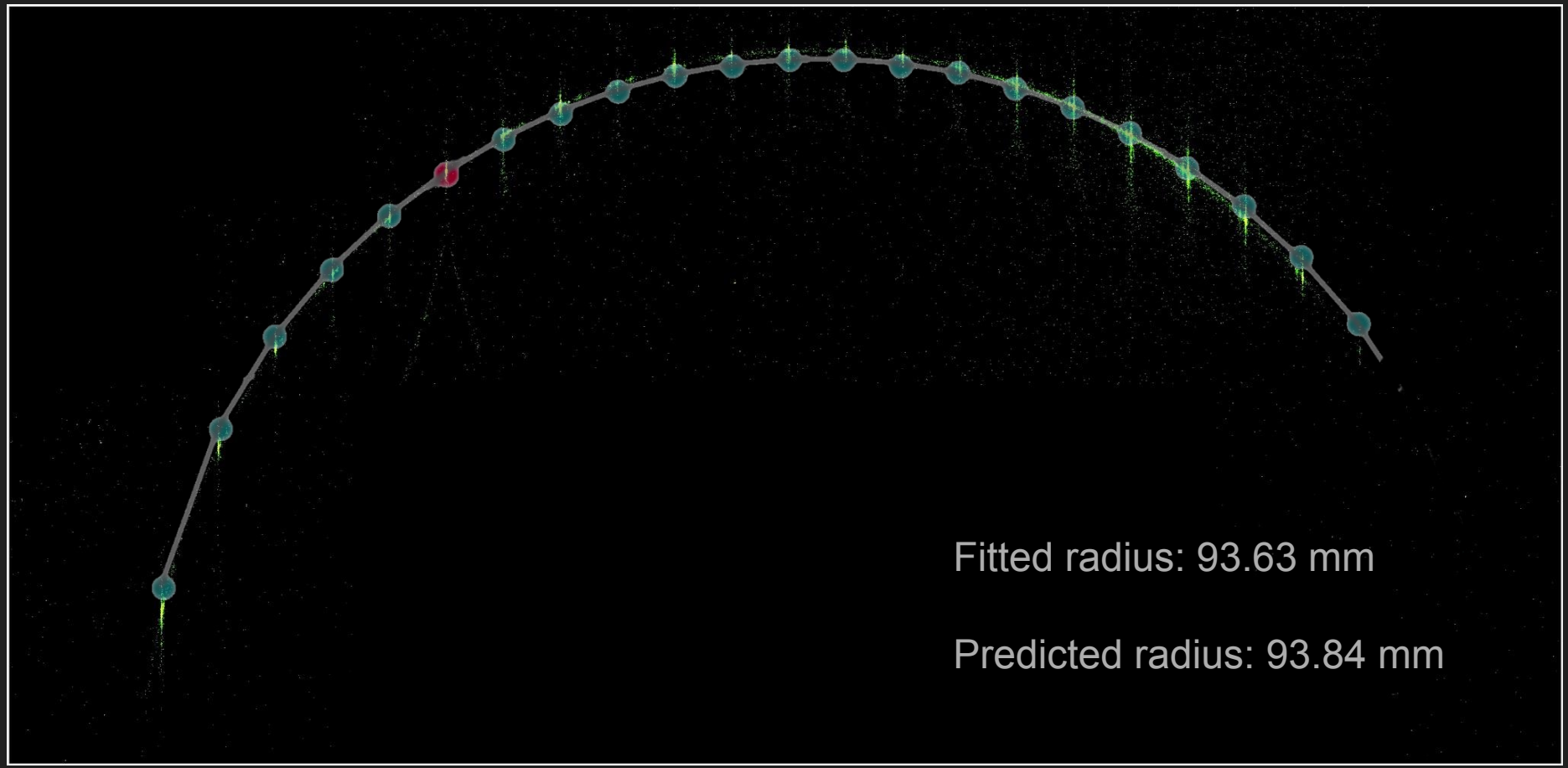
Why won’t you diffract?

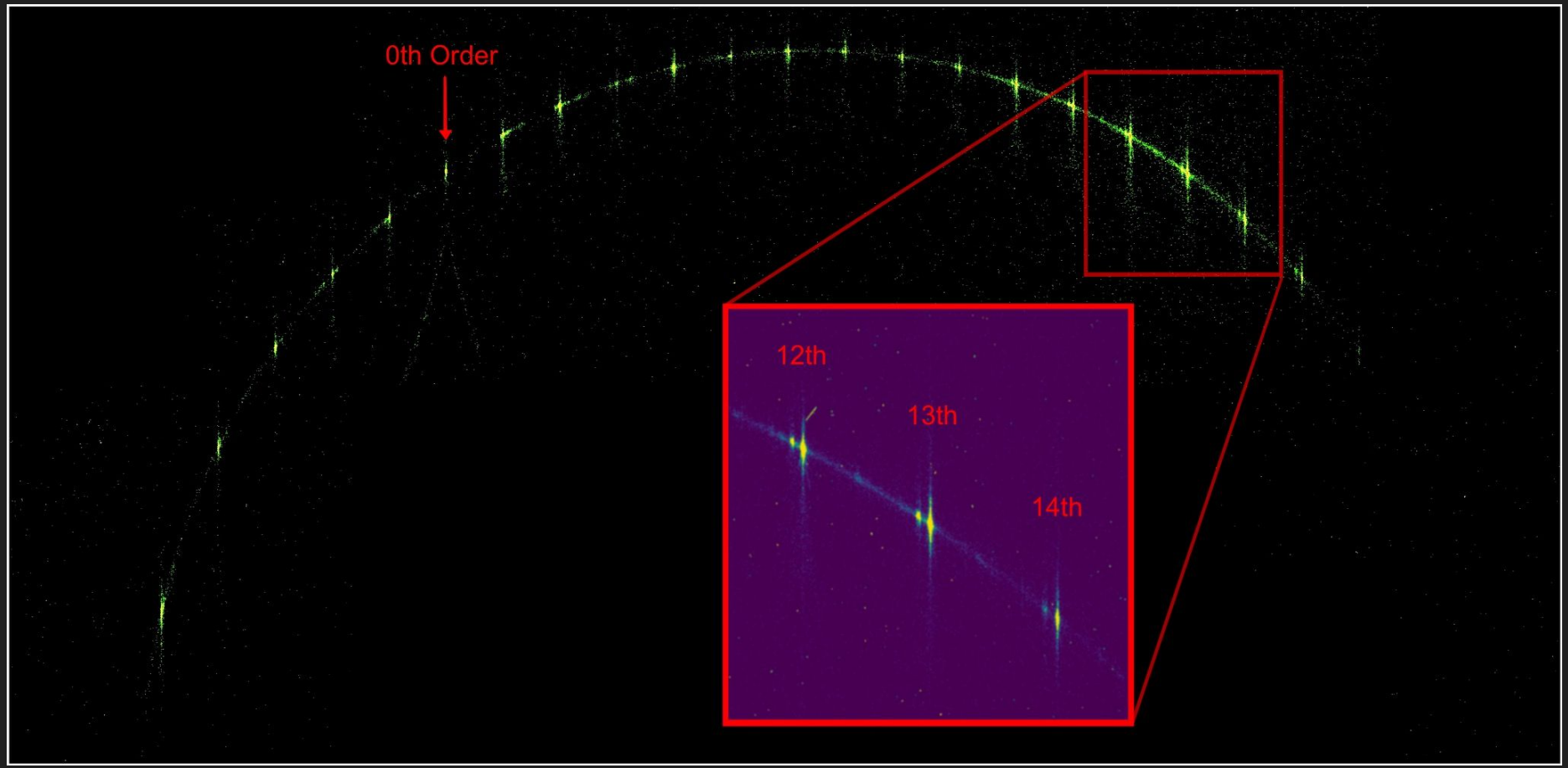


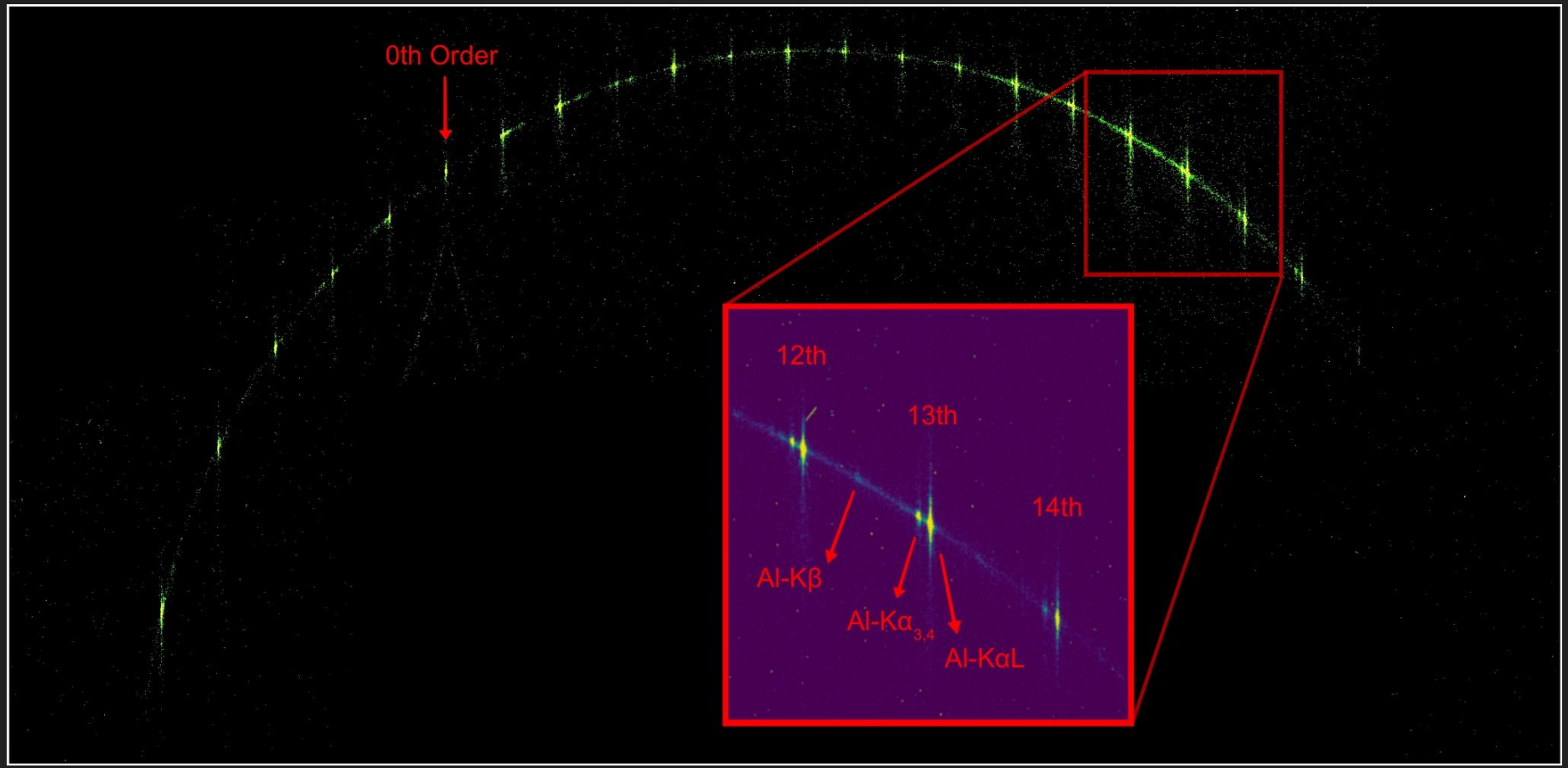
Why won’t you diffract?

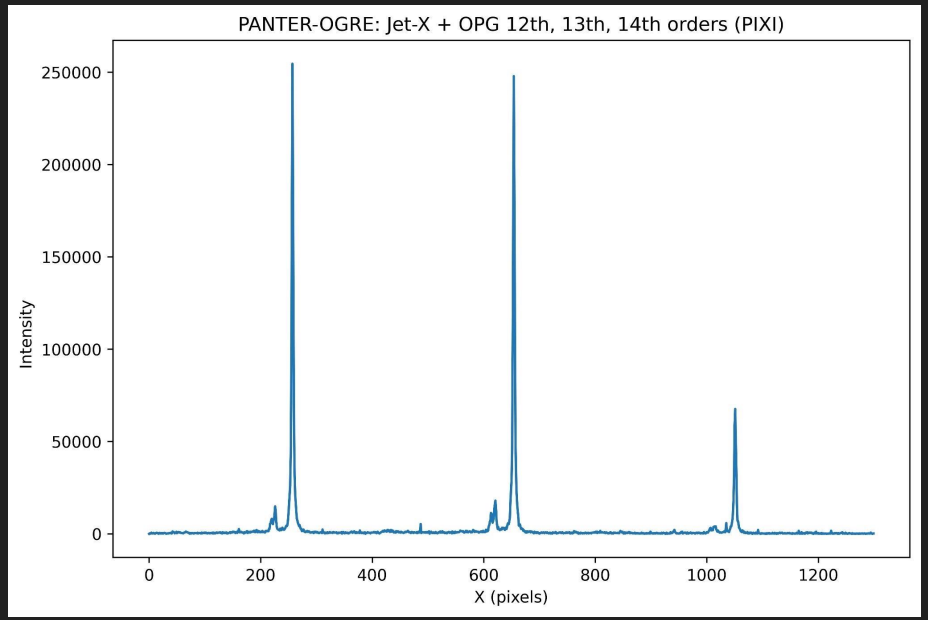


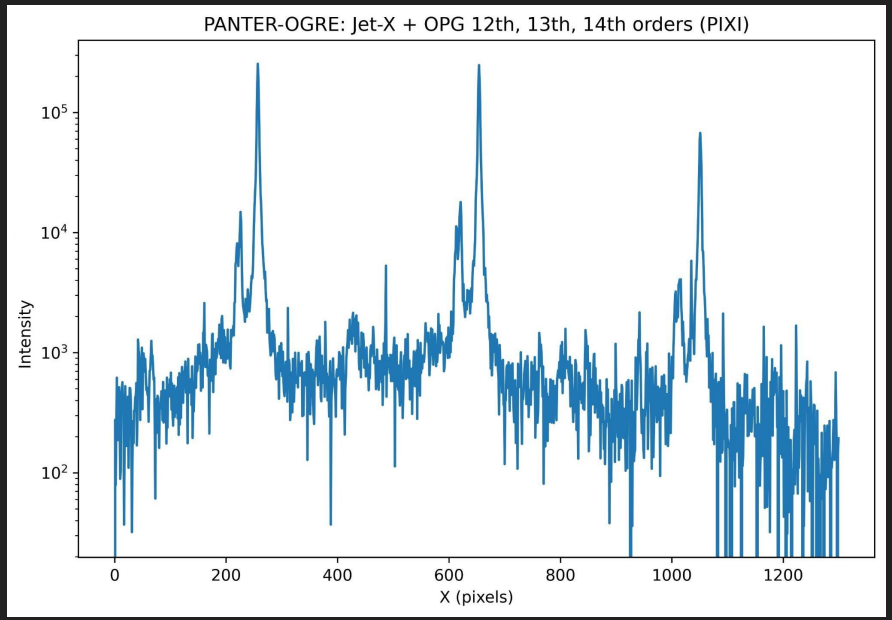



Fitted radius: 93.63 mm
Predicted radius: 93.84 mm

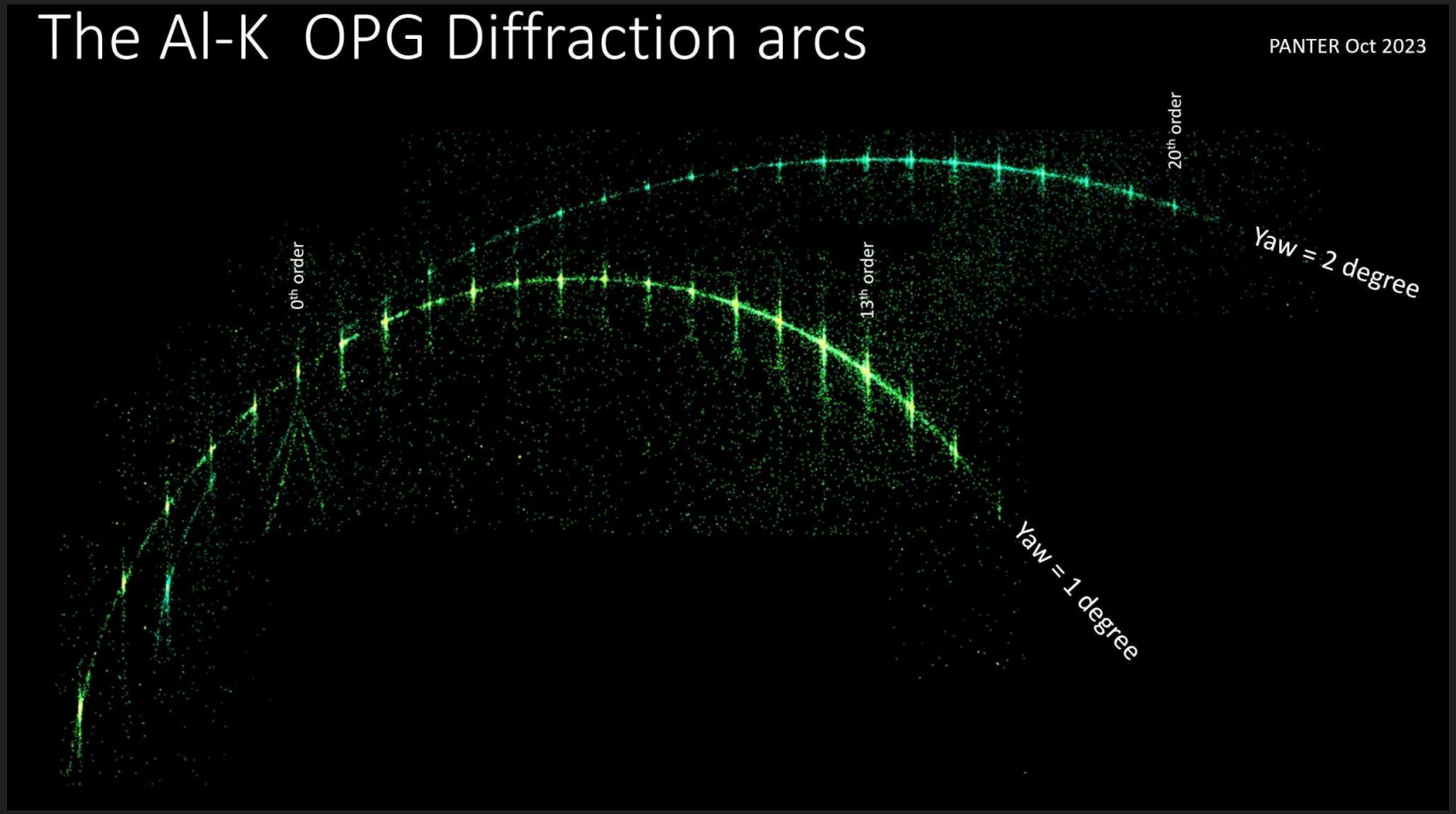

0th Order
12th
13th
14th


0th Order
12th
13th
14th
Al-Kβ
Al-Kα3,4
Al-KαL


PANTER-OGRE: Jet-X + OPG 12th, 13th, 14th orders (PIXI)
Intensity
X (pixels)
0
50000
100000
150000
200000
250000
0
200
400
600
800
1000
1200

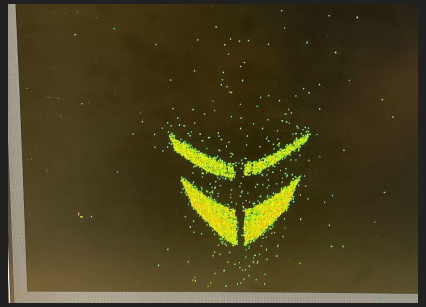

PANTER-OGRE: Jet-X + OPG 12th, 13th, 14th orders (PIXI)
Intensity
X (pixels)
10^2
10^3
10^4
10^5
0
200
400
600
800
1000
1200

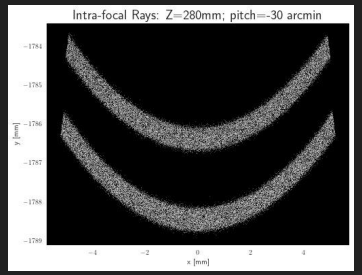
The Al-K OPG Diffraction arcs

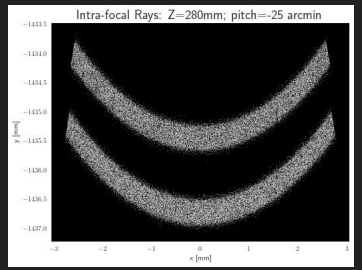


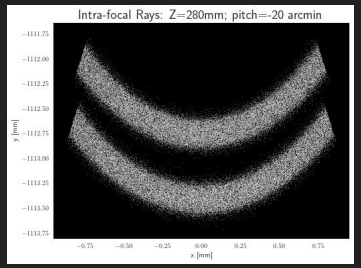
Switching to Polished Silicon Optic (PSO)

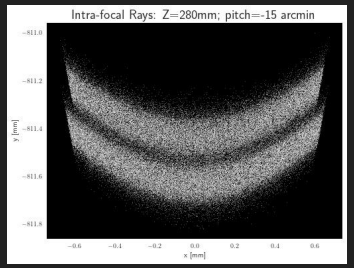
- Same alignment process
- Focus ~20 mm off from what was expected: needed to open the chamber again
- Had a pitch misalignment and we were seeing a smile image

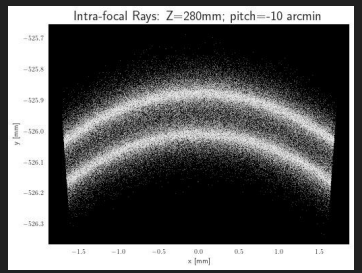


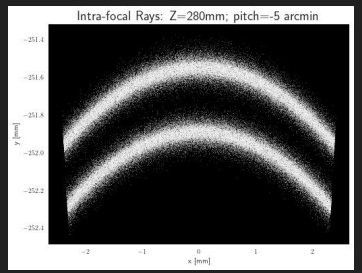


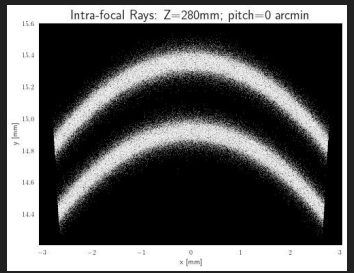




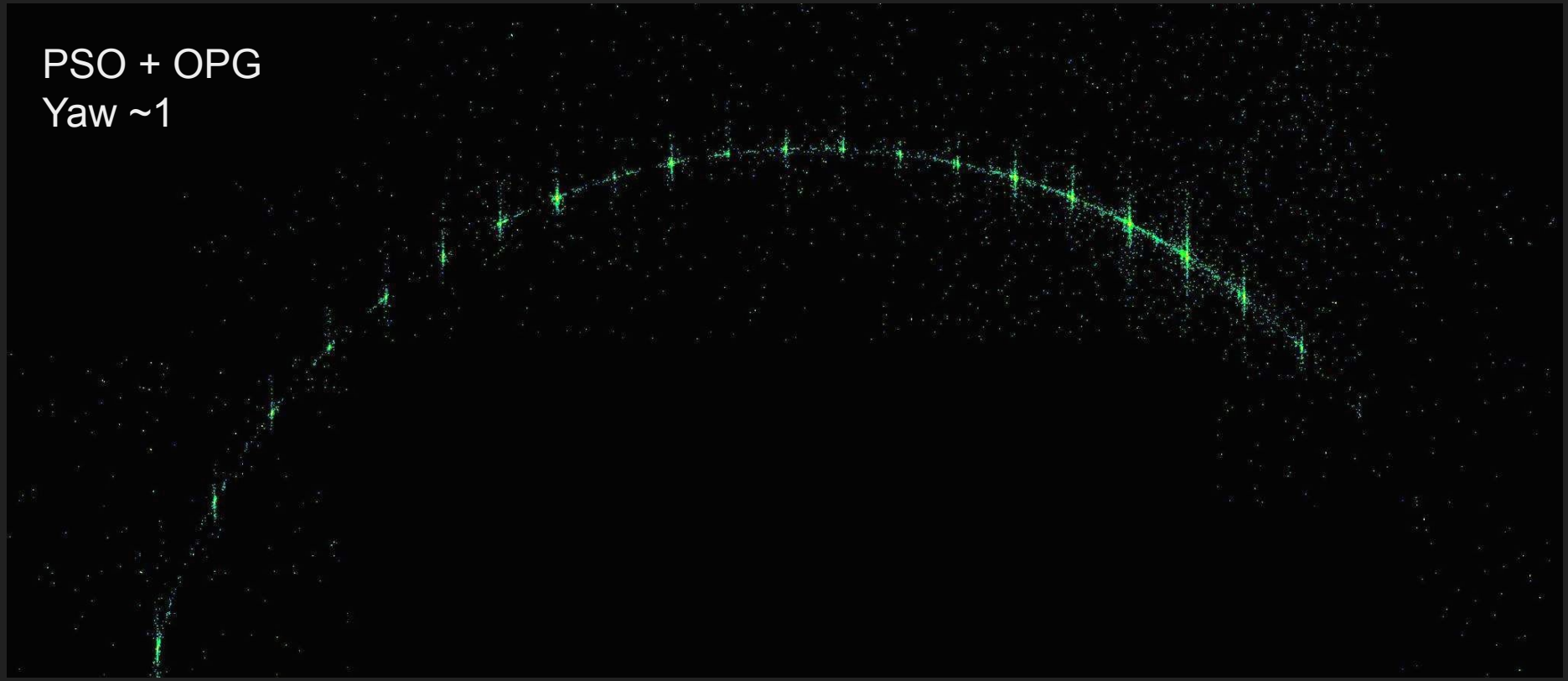


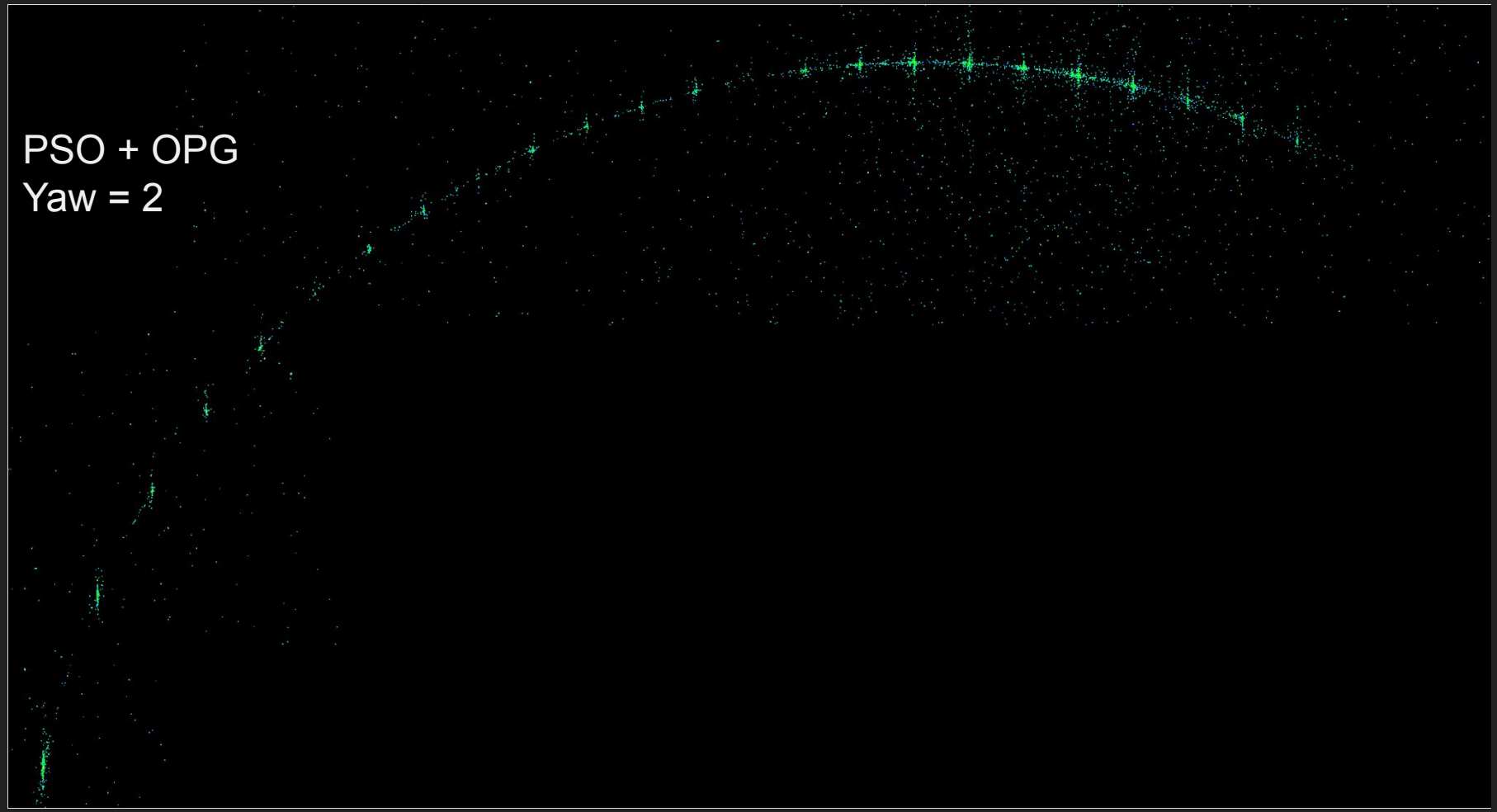


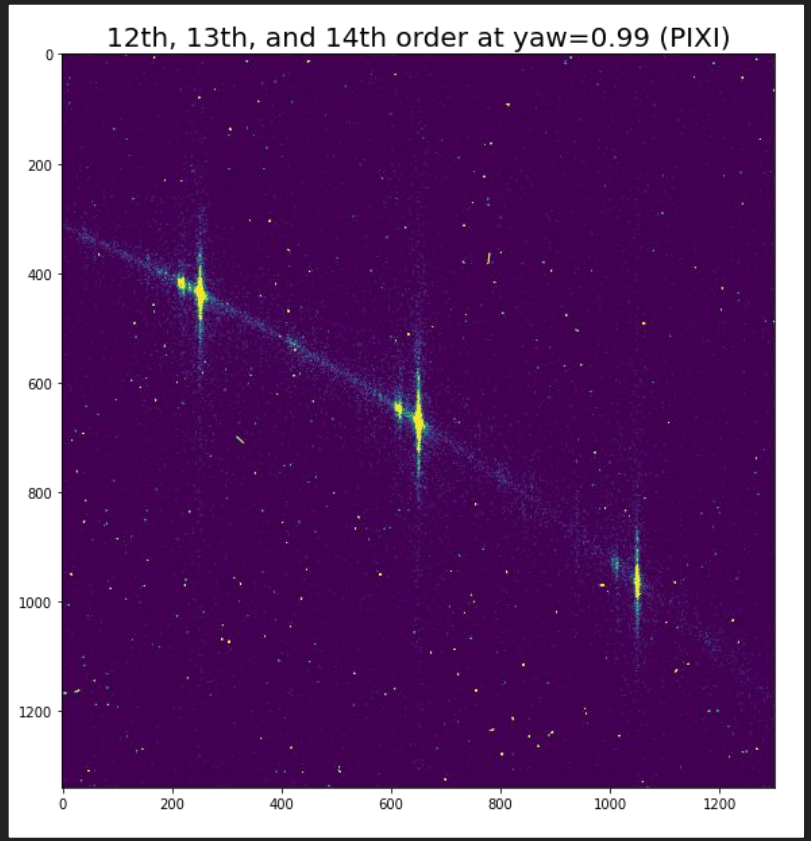


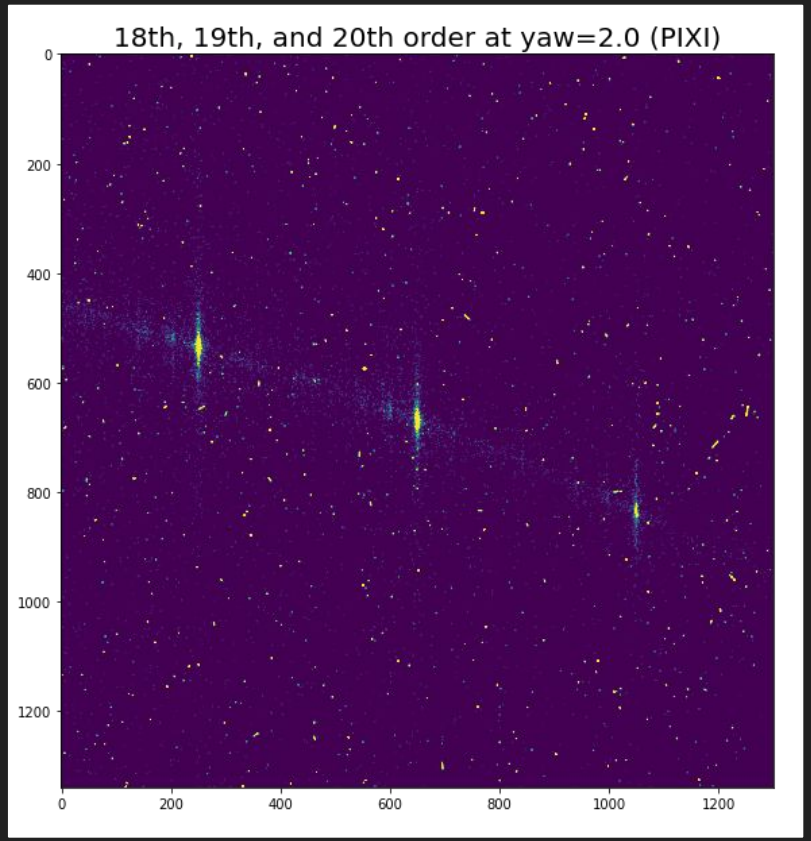


- Raytracing showed that a pitch misalignment could move where the focus was
- We were looking at an extra-focal image


PSO + OPG
Yaw ~1


PSO + OPG
Yaw = 2

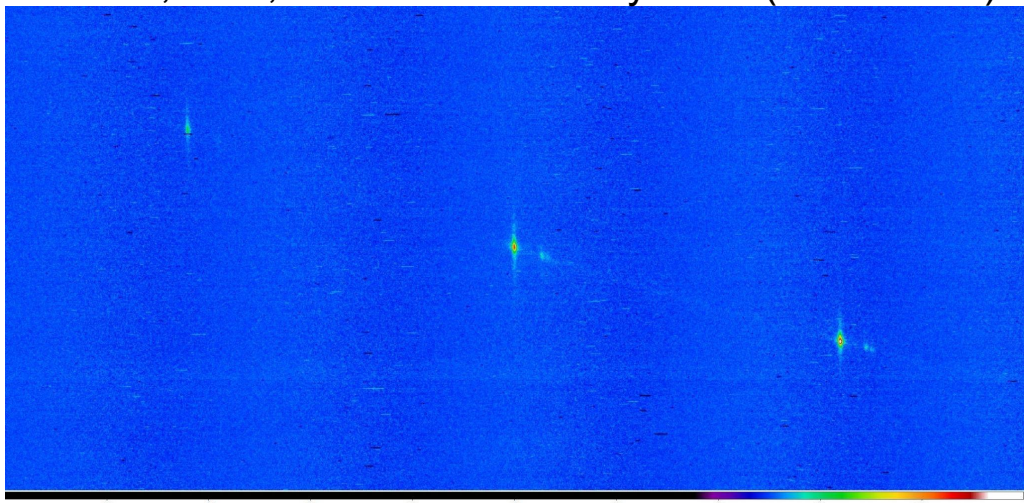

12th, 13th, and 14th order at yaw=0.99 (PIXI)
0
200
400
600
800
1000
1200


18th, 19th, and 20th order at yaw=2.0 (PIXI)
0
200
400
600
800
1000
1200

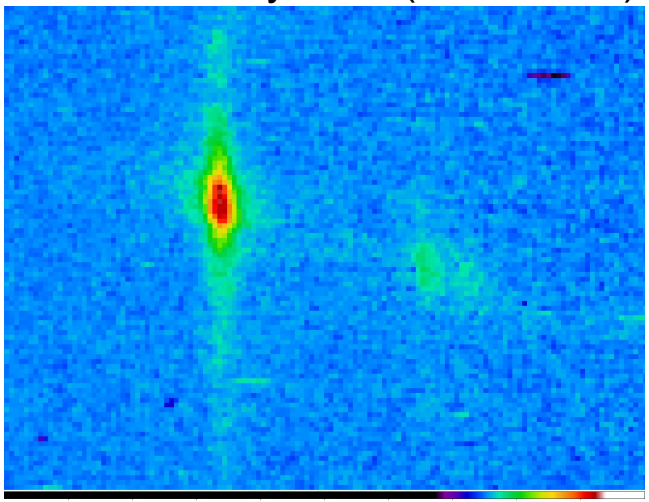
Added XCAM detector

- “OGREcam” — EM-CCD with 16 micron pixels
- Encoders emitting in infrared and banding

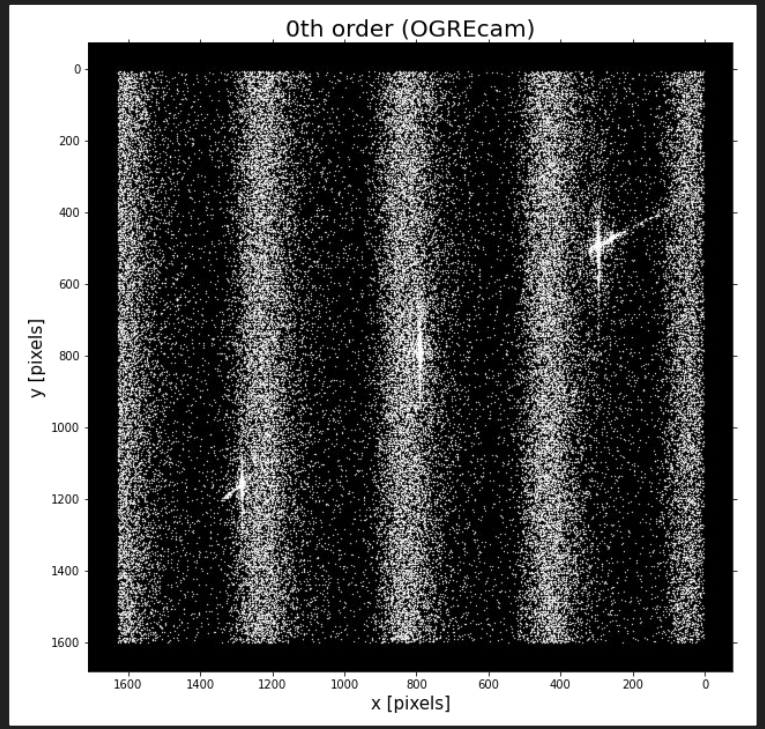
12th, 13th, and 14th order at yaw=1 (OGREcam)

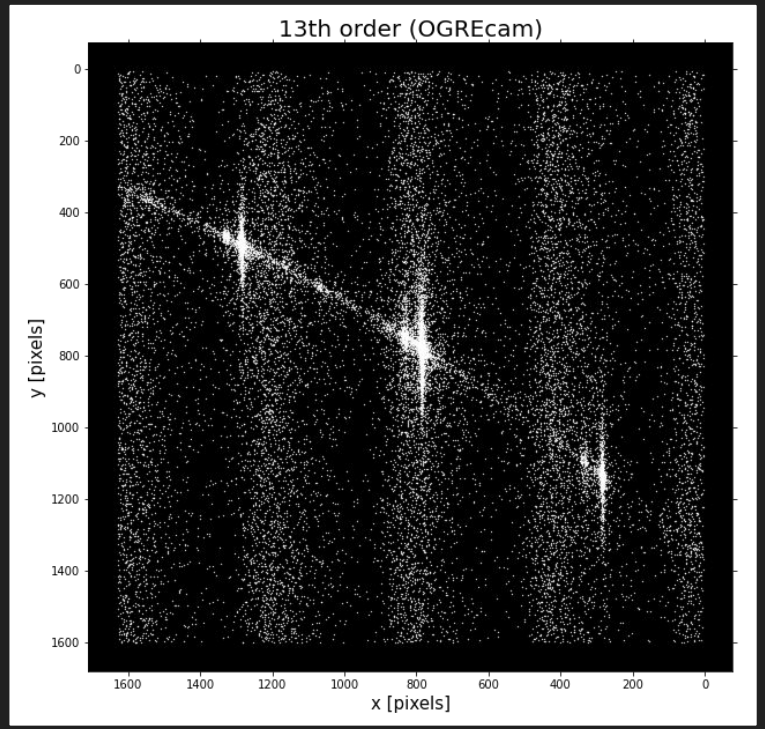


13th order at yaw=1 (OGREcam)



Added XCAM detector

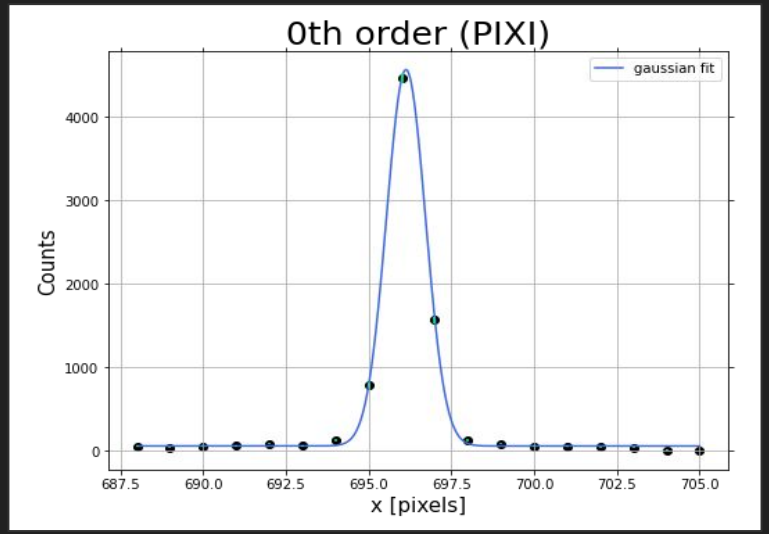




Spectral Resolution *Rough* Estimate

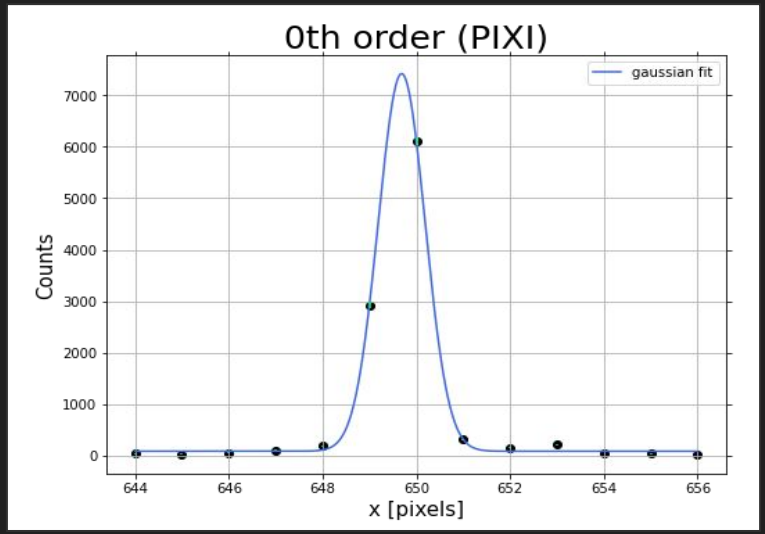
PIXI: 20 micron pixels; dispersion distance: 103.22 mm

JET-X + OPG



Gaussian FWHM: 1.39 pixels (27.8 microns)
R (x/Δx) ≈ **3712.9**

PSO + OPG

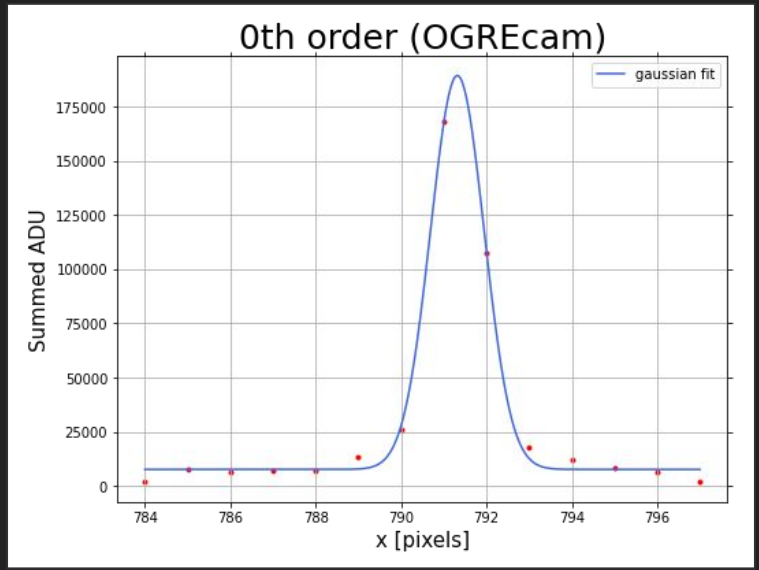


Gaussian FWHM: 1.39 pixels (27.8 microns)
R (x/Δx) ≈ **3712.9**

Spectral Resolution *Rough* Estimate

OGREcam: 16 micron pixels; dispersion distance: 103.22 mm

PSO + OPG + XCAM



Gaussian FWHM: 1.48 pixels (23.68 microns)

R (x/Δx) ≈ **4359.0**

Conclusion and Future work

- Rough, preliminary estimates of spectral resolving power indicate that OGRE spectrometers using both JET-X or PSOs meet performance requirements

- Lots of data — lots of future work
- TRoPIC data (larger pixels but has event counting)
- Fit a convolution of lorentzians and gaussians to 0th order profile
- Use compare 0th order and 13th order profiles to asses grating aberrations
- Still working to understand performance of the double shell PSO in the three configurations it was tested in.

Thank you for your attention!

Thanks to the entire PANTER team for everything — helping with the campaign, teaching me so much and also hosting me for six weeks

Thanks to XCAM + The Open University

Thanks to the rest of the McEntaffer group